A quantitative method to measure and characterize the daily functionality of cities

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1.- Introduction

The "daily functionality" concept don't exist in scientific literature. More usual are concepts like centrality or function. The simplest meaning of centrality refers to the point that, given its geometrical position in geographical space, or the provision of communications infrastructure, is able to minimize the effort to reach it from the remaining territory, and in that sense, is susceptible to centralize functions (eg is a good distribution of services).

The function can be defined as all activities that influence each other regularly through relationships that enable the social system to continue operating. Function is thus the equivalent of activity. Activities can be of administrative, commercial, industrial, tourism, etc., so that each centrality (good connection point) can concentrate one or more activities.

The functionality is the interaction that is generated between parts of the city, to meet the needs of located residents and activities. The functionality (or interaction) usually proceeds through flows of matter, energy, information, and people between the nodes (functions). In other words, is affecting by how people are willing to use their time for travel, to choose their destinations and routes, in the daily routine.

In this sense, the daily functionality is the form of how people satisfy their needs in the different activities inside the city throughout the day.

Various scientific disciplines cover this matter with different approach, like as the use of time, the use of space, and the integrations of both. But there are some problems in their approaches, in terms to respond to the social, spatial, and temporal scale required by the daily functionality of cities. Some of these problems are:

- The research on time use has mainly an individual approach, without representation for the entire population [6].
- The current activity-based paradigm of transportation research examines how aggregated human phenomena emerge from individual activity participation in space and time [1]. Despite this intention, the studies are based mainly on time (travel and activity), and the sequence of activities carried out by people in the day.
- The social and anthropological approach of the use of space also has mainly an individual approach. A new theme has emerged in this line of research, who studies the use of spaces to access to activities [4], but with the same social scale (individual).
- In the well know land use transportation model (LUTM), the daily dynamics view is unusual [3]. Also the accessibility concept, used in this and in another type of models, is divergent and ambiguous [2].
- The use of space and time represented in the "time geography" approach (Hägerstrand, 1969), is a powerful conceptual and analytical basis for the understanding of urban social phenomenon [5][1], but mainly with an individual approach.

2.- Purpose and methodology

A simple approach to understand and to characterize the behaviour of the people in the city throughout the day, is to recognize that it has two analytical dimensions (space and time), and two physic actions (to access and to develop the activities). So, the combination of both (dimensions and actions) characterized de daily functionality in terms of "time to access", "time to develop (duration)", "space to access", and "space to develop" the specifics activities [2].

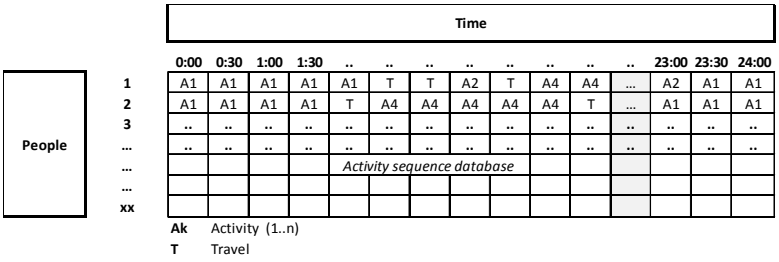
The purpose of the present research is to measure and to characterize the spatio-temporal behaviour of the daily functionality of people, by different activities and social class.

The methodology applies a trip chain and a time geography approach to processing and to analyze household travel surveys of metropolitan areas.

The following process has been applied to the travel surveys to obtain quantitative measure of the daily functionality:

- The applied trip chain approach to the travel survey has two objectives; the first is to allow the validation of the travel database, in order to identify time and spatial codification mistakes. The second is to construct (or to validate) the information about the time that each passenger spends in each activity (associated with the trip purpose), information which was not incorporated in some surveys. So, the first step was constructing the trip chain for each person. With the final trip chain was building the sequence of activities every 30 minutes (the activity being developing at each half hour). Figure 1 show a diagram of the database

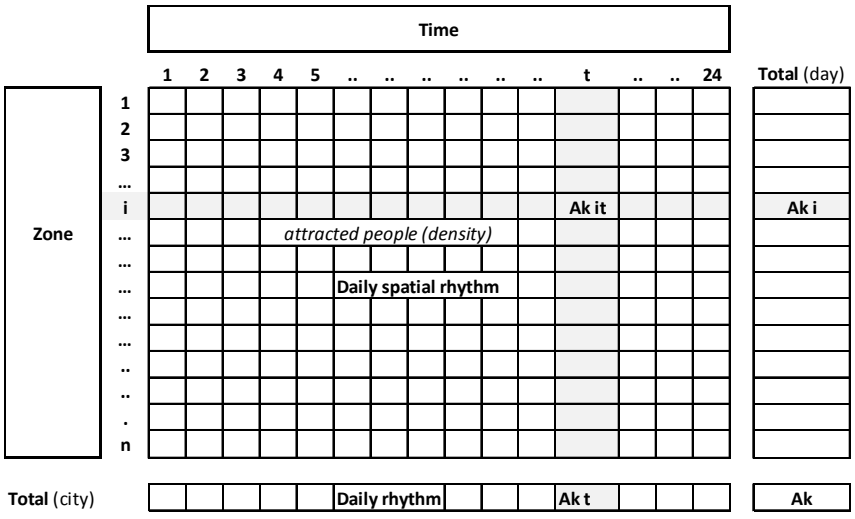
Figure 1.- Activity sequence database



- With the activity sequence database was building the **daily rhythm** of the city. This term was generated by the time use research to characterize the sample of people to be analyzed. Represents the distribution of people (number and/or percentage), in different activities, at every half hour of the day. Travel is considered as an activity.

- With the activity sequence database also was building the **daily spatial rhythm** of people in the city, which is the spatialization of the daily rhythm. The query is where are people, developing what activity, in every half hour of the day. The result is a temporal space density of people by activity. This information is valid only when the travel survey has a good spatial representation of travellers. Figure 2 show an explanation diagram of the different products mentioned.

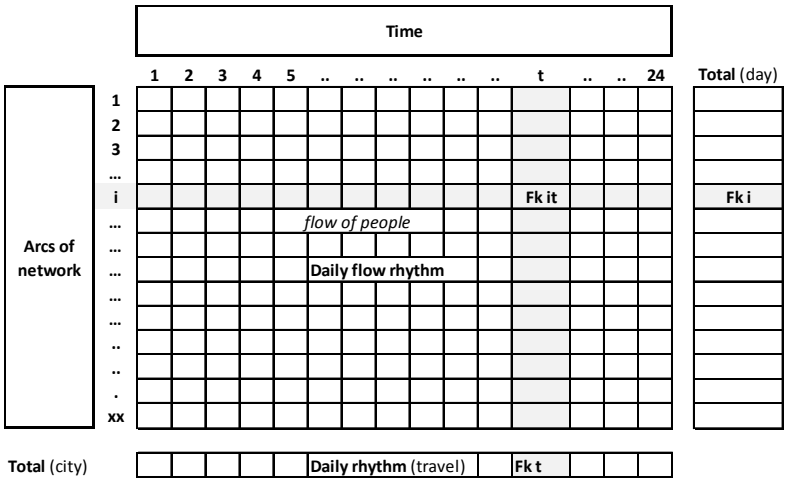
Figure 2.- Structure of the daily rhythm databases



Where Ak_i^t is de number of people (and density) in the zone i, developed the activity k, in time t. Ak_i is the number of people (density) who came to zone i, to develop the activity k in the day. Ak^t is the number of people who develop the activity k, at time t. Ak is the number of people who came in the city, to develop the activity k in the day.

- While travel is one of the activity that people develop throughout the day, with the activity sequence database also was building the **daily flow rhythm** of people in the city, which is the spatialization of travels from the daily rhythm. The approach here is like the dynamic traffic assignment methods, but in this case the different matrices are instant matrices (how many people are travel between each O/D, in each half hour of the day, by each activity). The results are temporal distribution matrices, by activities. These matrices were assigned to the transport network, with an "all or nothing" method without capacity restrictions. The intention here is to characterize main corridors, and not to apply a traditional transport assignment model. Finally, the process generates temporal flows (by activity) in the structural network of the metropolitan area. Figure 3 show an explanation diagram of the database.

Figure 3.- Structure of the daily flow rhythm database



Where Fk_i^t is the flow of people in the arc i, who are travel to the activity k, in time t. Fk_i is the daily flow of people through the arc i, who travel to the activity. Fk^t is the number of people who are travel to the activity k, at time t.

- The above processes was applied for different types of day (week and weekend), activities (work, study, shop, social, personal, leisure, etc), social class (educational level as a proxy), and specifically for people over 16 years old.

To characterize the daily functionality, different synthetics indexes (or analysis) have been applied. The following section describes these indices.

2.1.- Characterization of the daily trip chain.

2.1.1.- The **sequence** of activities

- Descriptive: the number of stages, the purpose/activities structure, the sequence of activities and sequence of transport modes, etc.
- Transition probability matrix between activities: the equation and the structure of this matrix is:

$$Prob(Ai, Aj) = \frac{P(Ai, Aj)}{Ai}$$

	Activity					
Previous activity	1	2	..	j	..	Total
1	*P(A1,A1)*	*P(A1,A2)*	..	*P(A1,Aj)*	..	A1
2	*P(A2,A1)*	*P(A2,A2)*	..	*P(A2,Aj)*	..	A2
...	..	..	..	..	..	..
i	*P(Ai,A1)*	*P(Ai,A2)*	..	**P(Ai,Aj)**	..	**Ai**
...	..	..	..	..	..	..
						A

Where P(Ai,Aj) is the number of people who develop the activity i before the activity j, and Ai is the total number of people whose previous activity is i.

2.1.2.- The **access** to activities

- Percentiles of time and distance distributions
- Functional probability of access: the functional probability is constructed as the inverse cumulative distribution of travel times and distance to each activity. This distribution is used as an access measure, and represent the "willingness to spend time or to travel a distance" for access to specific activities in the city.
- Bivariate distribution of time-distance: this is a crosstab which characterizes the co-distribution of time and distance access to activities.
- A traditional dissimilarity index was used to compare functional probabilities between activities. The equation is:

$$D_{12} = \frac{1}{2} * \sum_{t} |P_1^t - P_2^t|$$

where D_{12} is the dissimilarity index between the distribution 1 and 2. P_1^t is the probability from the distribution 1, in time (or distance) t. This dissimilarity index became values between 0 and 1, where 0 is a high similarity, and 1 a high di-similarity between distributions.

2.1.3.- The **duration** of activities

- Percentiles of time distribution
- Functional probability of duration: is the same inverse cumulative distribution of the duration of each activity. This distribution represent the "willingness to spend time to develop" specific activities in the city.
- Comparing functional probabilities between activities: with the dissimilarity index

2.1.4.- The **relation between access and duration** time of activities

- Correlation analysis (Pearson index)
- Comparing functional probabilities between access and duration by activities: with the dissimilarity index

2.2.- Characterization of the daily rhythm

- Correlation analysis (Pearson index)
- Time coexistence percentage by activity (TCk): the ratio between the total travel that comes in the city throughout the day, and the maximum number of people who develop this activity in a given time. The equation is

$$TCk = \frac{\max_t Ak^t}{Ak} * 100$$

where Ak^t is the number of people who develop the activity k, at time t. Ak is the number of people who came in the city, to develop the activity k in the day.

2.3.- Characterization of the daily spatial rhythm

2.3.1.- Spatial specialization

- Specialization index by activity-zone: is the ratio between the proportion of a specific activity in a specific zone, and the proportion of the same activity in the city. The equation is:

$$S(Ak,i) = \frac{Ak_i/A_i}{Ak/A}$$

where S(Ak,i) is the specialization index of the activity k in the zone i. Ak_i is the number of people (density) who came to zone i, to develop the activity k in the day. Ak is the number of people who came in the city, to develop the activity k in the day. A_i is the number of people who came in the zone i, and A the daily number of people who came in the city.

2.3.2.- Spatial coexistence

- Spatial correlation analysis between activities by activity (Pearson index)
- Factorial analysis: to integrate the statistical behaviour of activities (correlation) in principal common factors, which characterize the different zones of the city.
- Exposure index: is the traditional exposure index (Bell 1954) applied in segregation research, but here is applied to the people who develop different activities in a same zone. Te equation is:

$$P_{A2}^{A1} = \sum_{i=1}^{n} \left[\frac{A1_i}{A1} * \frac{A2_i}{A_i}\right]$$

where P^{A1}_{A2} is the exposure index between the activity 1 and 2. $A1_i$ is the number of people in activity 1, in zone i. A1 is number of people in activity 1 in the city, Ai is the numbers of people in zone i. These indexes generate a matrix, in which diagonal is the isolation (exposure between the same activity). One particularity of this index is that, for a specific activity, the sum of isolation and the exposure indices is 1, so it shows the trade-off between isolation and exposure.

2.3.3.- Spatial structure

- Traditional cut-off methods to identify spatial sub-centres, based on density measure.

2.4.- Characterization of the daily flow rhythm

- Specialization index by activity-corridor: the same specialization index, applied to the different flows by activities.

3.- Some results for Barcelona 2001

3.1.- Characterization of the daily trip chain

- For all days (week and weekend), the highest proportion is for working purpose with 38%, followed by studying (25%), and then shopping and social purposes (11% and 10% respectively). Weekend change this structure, being leisure and entertainment the highest proportion (27%), then shopping (20%), followed by working and social reasons (both with 16%).
- For all days, 74% of daily trip chains have two stages, and 19% have four stages. The two stage chain reaches 81% in weekend, and 72% in the weekday. The four stage chain decreases from 20% in week to 12% in weekend.
- Regarding the sequence of activities, the highest percentage is for home-work-home with 24%, followed by home-study-home (14%), and home-shop-home (12%). Weekday maintains this structure, but the weekend change this, being the highest proportions for home-shop-home, and home-leisure-home (both with 19%), followed by home-work-home (11%), and home-social-home (10%).
- The transport modes associated with the above sequences shows that walking has the highest proportion in shopping (55%) and leisure (70%) chain. Private car is predominant in work chain (in average 46%). Bus doesn't have a clear predominance in the different activity chain, but reach his highest percentage in sanitary (33%) and social (22%) chain. Metro also doesn't have a clear predominance, but reach his higher proportion in study (25%) and personal activities (15%) chain.
- Table 1 show the transition matrix for different type of day.

Table 1.- Transition matrix by activities and type of day

Week	**Activity**							
Previous activity	Home	Work	Study	Shop	Personal	Social	Leisure	
Home (origin)	0,00	**0,50**	**0,13**	**0,15**	**0,10**	0,08	0,04	1,00
Home	0,01	**0,45**	0,09	0,07	0,08	**0,21**	**0,10**	1,00
Work	**0,93**	0,03	0,01	0,00	0,01	0,01	0,01	1,00
Study	**0,95**	0,01	0,01	0,00	0,00	0,01	0,01	1,00
Shop	**0,95**	0,01	0,00	0,02	0,01	0,01	0,01	1,00
Personal	**0,89**	0,02	0,00	0,02	0,03	0,01	0,01	1,00
Social	**0,87**	0,04	0,00	0,02	0,01	0,04	0,02	1,00
Leisure	**0,85**	0,07	0,01	0,01	0,01	0,02	0,04	1,00

Weekend	**Activity**							
Previous activity	Home	Work	Study	Shop	Personal	Social	Leisure	
Home (origin)	0,01	**0,19**	0,03	**0,27**	0,08	**0,16**	**0,26**	1,00
Home	0,01	**0,25**	0,03	0,09	0,08	**0,18**	**0,37**	1,00
Work	**0,93**	0,02	0,01	0,00	0,01	0,01	0,02	1,00
Study	**0,93**	0,02	0,02	0,01	0,01	0,01	0,00	1,00
Shop	**0,93**	0,00	0,00	0,02	0,01	0,01	0,02	1,00
Personal	**0,89**	0,00	0,00	0,02	0,03	0,03	0,03	1,00
Social	**0,88**	0,01	0,00	0,02	0,01	0,04	0,05	1,00
Leisure	**0,89**	0,01	0,00	0,01	0,00	0,02	0,07	1,00

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The matrices shows a high probability of the stay at home as previous activity of all the other activities. In the weekday, the most probable activity after home is to work, followed by study, shop, and personal activities with similar proportion. The weekend change this behaviour, being shop or leisure activities most probable.

All the activities return to home, previous develop of another activity. So, Barcelona presents a pendulum pattern of trip chain.

- In general, there are no correlation between travel time and duration of activity (0.02 all activities, 0.16 working, 0.09 studying, 0.19 shopping, 0.11 leisure). Table 2 show the results of the functional probability of time.

Table 2.- Functional probability of time to access and duration, by daily activities

	Travel to activity					Activity duration				
Time (min)	Work	Study	Shop	Social	Leisure	Work	Study	Shop	Social	Leisure
5	99,9	99,7	99,9	99,7	99,8	99,6	99,7	98,6	83,4	98,6
10	95,2	96,6	92,6	94,9	95,2	99,5	99,4	97,7	75,6	98,0
15	79,3	83,2	62,8	73,1	77,8	99,3	99,4	95,7	70,4	97,6
20	59,5	64,8	40,1	50,7	56,8	99,1	99,3	93,9	66,6	97,0
25	47,9	54,2	27,2	39,0	42,8	99,0	99,3	89,6	65,1	96,7
30	44,7	50,8	25,0	35,5	39,8	99,0	99,3	88,2	64,6	96,5
35	19,5	28,2	9,1	14,5	17,4	98,7	99,2	83,2	62,2	94,6
40	17,6	26,4	8,3	13,3	16,2	98,6	99,2	81,5	61,7	94,3
45	14,3	22,0	7,1	11,3	13,9	98,4	99,1	78,0	61,1	93,3
50	9,3	16,3	5,1	7,4	9,2	98,2	98,5	72,9	59,9	91,8
55	8,2	14,5	4,7	6,3	7,6	98,1	97,7	65,2	58,6	89,8
60	7,9	14,0	4,5	6,0	7,4	98,0	97,4	63,2	58,1	88,7
65	2,3	5,0	2,1	2,3	2,9	97,6	95,6	59,2	55,7	85,0
70	2,0	4,6	2,1	2,2	2,8	97,5	95,3	57,5	55,1	84,1
75	1,8	4,1	1,8	1,9	2,6	97,3	95,0	54,6	54,2	83,1
80	1,3	3,1	1,7	1,4	2,1	97,0	94,6	50,5	52,8	80,6
85	1,1	2,9	1,6	1,3	2,0	96,8	94,5	45,2	51,8	78,6
90	1,1	2,8	1,6	1,3	1,9	96,8	94,4	44,2	51,3	78,1
95	0,5	1,6	0,9	0,6	1,4	96,2	92,8	38,8	48,2	73,9
100	0,5	1,6	0,9	0,6	1,4	96,1	92,6	37,7	47,6	72,8
105	0,4	1,4	0,9	0,6	1,3	95,9	91,8	34,1	45,9	70,3
110	0,3	1,3	0,8	0,5	1,1	95,4	91,1	28,8	43,6	66,2
115	0,3	1,3	0,8	0,5	1,1	95,2	90,1	24,1	41,5	63,1
120	0,3	1,3	0,8	0,5	1,0	95,0	90,0	23,3	41,3	61,9

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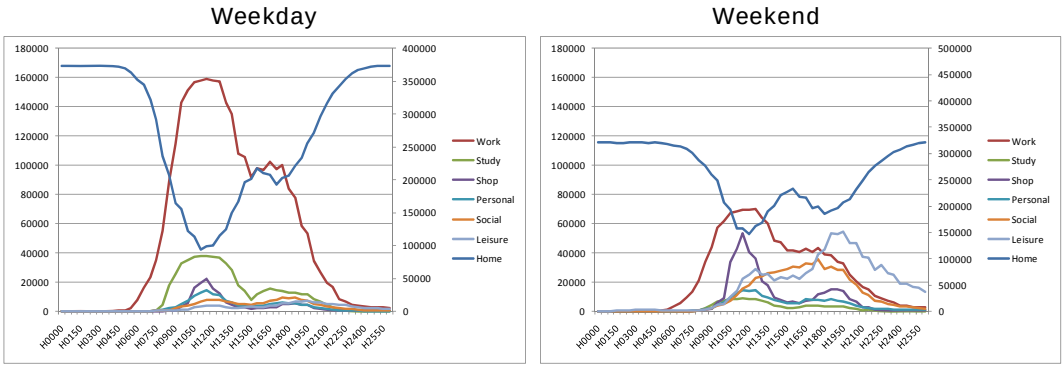
The probability that an activity takes an hour, is 98.0% if it is working, 97.4% if is studying, 63.2% if is shopping, 58.1% if is social, and 88.7% if is leisure. Moreover, a one-hour trip has a probability of 7.9% if it is to access to work, 14.0% if it is to access to study, 4.5% if it is to access to shop, 6.0% if it is to access to social activity, and 7.4% if it is to access to leisure activities.

The median value of travel distance is 3.750 mt for access to work and to study, 1.250 mt for access to shop, and 2.000 mt and 2.500 mt for access to social and leisure activities.

3.2.- Characterization of the daily rhythm

- The daily rhythm for Barcelona 2001 is show in figure 4

Figure 4.- Daily rhythm, Barcelona 2001



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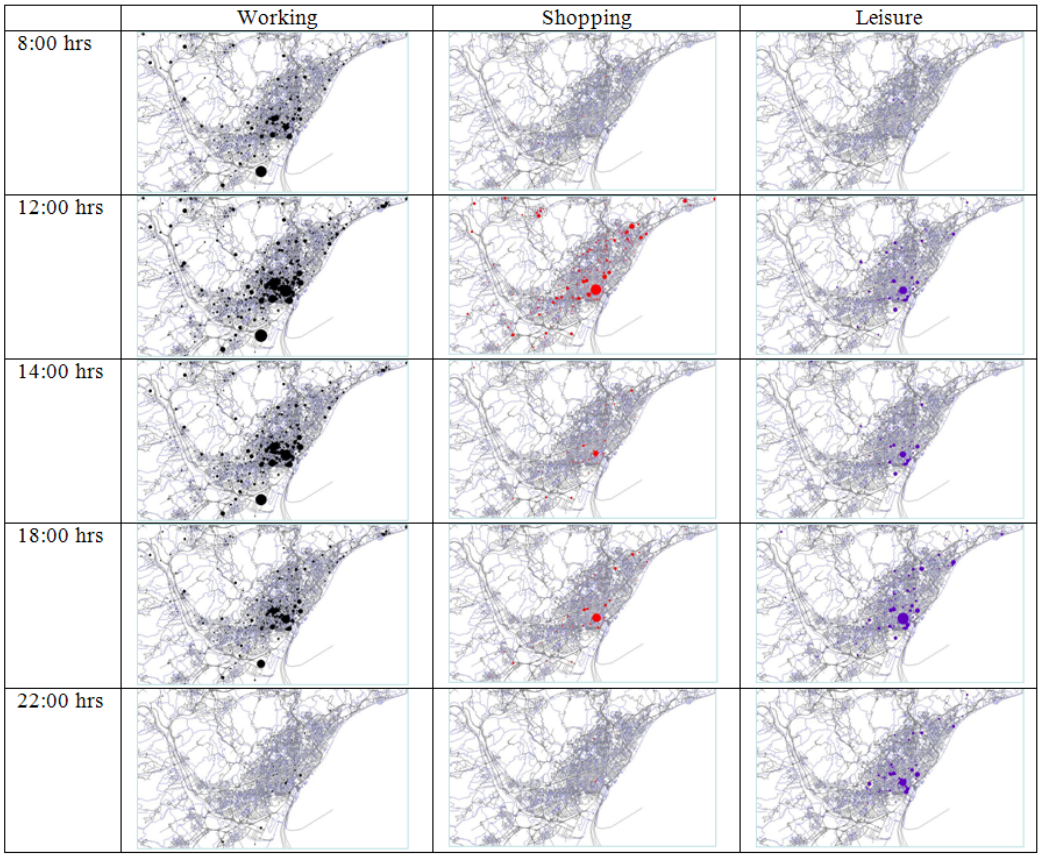
The results show that working presents its major intensity at 11:30 hrs., and a second maximum (65% of the maximum) at 14:30 hrs. Study has the maximum at 11:30 hrs., and a second maximum (59%) at 16:00 hrs. Shopping has the maximum at 11:50 hrs., and a second maximum (25%) at 18:30 hrs. Personal activities has the maximum at 11:30 hrs., and a second maximum (50%) at 17:30 hrs. The social activities has an inverse pattern, because it maximum is reached at 17:30 hrs., and a second maximum (70%) at 12:30 hrs. Finally, the leisure and entertainment activities have its maximum at 18:30 hrs, and a second maximum (50%) at 11:30 hrs.

- The time coexistence percentage shows that, in weekday, workers maximum intensity reaches 94% of total trips (in weekend drops to 78%). Student maximum intensity on a weekday is 92%, and 74% in weekend. Shopping maximum intensity on a weekday is 54%, and 56% in weekend. Personal activities have an intensity of 44% in weekdays, and 43% in weekends. Social purpose has a 25% in weekdays, while reaching 48% in weekends. Finally the purpose leisure and entertainment reaches 36% in the weekday, and 44% in weekend.

3.3.- Characterization of the daily spatial rhythm

- Figure 5 show the daily spatial rhythm of people density (people/km^2), by three activities and five hours in a weekday.

Figure 5.- Daily spatial rhythm for work, shopping, and leisure, in Barcelona 2001



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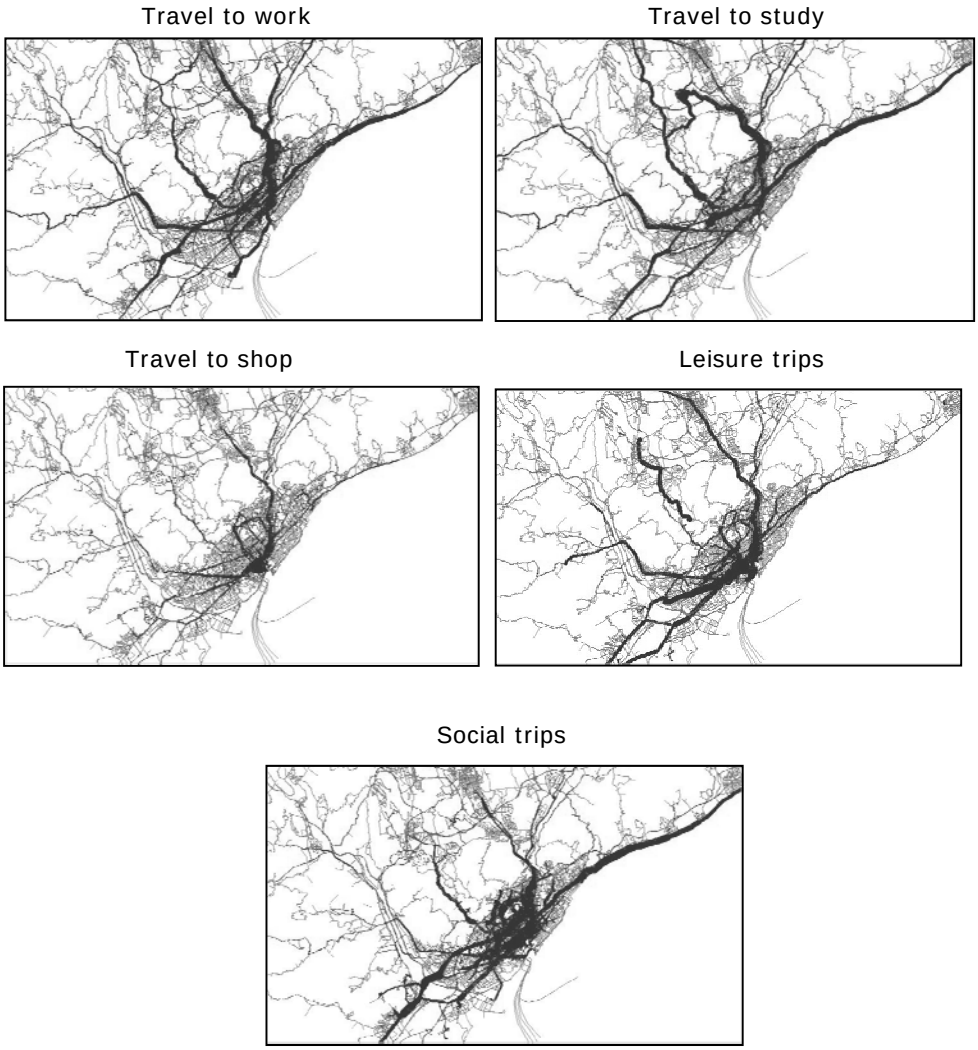
The high mean spatial correlation index (between all the activities) reaches 0,6 (pearson), during the period between 11:00 and 12:30 hrs. The same spatial relationship of activities takes place between 16:30 and 20:00hrs, with a mean spatial correlation around 0.7. In weekend this behaviour changes, work and personal activities don't coexist with the other activities, but shopping and leisure reaches a correlation of 0,8.

3.4.- Characterization of the daily flow rhythm

Figure 6.- Specialization corridors by work, shopping, study, and leisure, in Barcelona 2001



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The results show the specialization by the activities of the different transport corridors in Barcelona. On a specific corridor, it is possible to obtain a specialisation profile who indicates the potential social benefits of investment in transport, in terms of reducing travel times for different activity access. With this approach, the real benefits of transportation projects can be evaluated in terms of the trip chain, and not only in specific sections of the network.

4.- Conclusion

The developed space-time method achieves a good measurement and characterization of the daily functionality of cities. The synthetics indices constructed based on the different space-time results show a dynamics dimension of the behaviour of the different activities in the city, trough the behaviour of people who develop it.

The validity and reliability of the results depends directly on the basis of the travel survey to be used.

The functional approach generates several arguments to be highlight.

- Several studies of travel time traditionally use the average travel time [7], but as shown, the travel time is a random variable of mobility, whose statistical distribution is usually not symmetrical. So, it would be wrong to use the average time as a representative value.

- The social view of travellers, with different purpose, in the form of how they use de city in space and time, is a more real criterion to take account in different politics decisions, like as prioritising different transport corridors, doing the analysis of who uses them, for what, and in what time, or to evaluate the main projects inside a master plan of the city.

- The dynamics view of the city gives more information to be included in the planning and management process, to pre-evaluate desirable or not desirable situation in the city.

Finally, the city of Barcelona (2001) presents a pendulum pattern of trip chain, in which, private car is preferred for conditional (in time and location) activities, like working, perhaps because it offers a certainty in access time. Walking is preferred for un-conditional activities (shopping, leisure, social).

The results show a high constriction of time to travel in relation to the duration of activities, and also show a clear differences by activities, being more restricted the times to shopping and social activities, and larger to work, study, and leisure.

There are clear dissimilarities by daily activities behaviour in terms of intensity of use of time, correlations in the use of space, and in the functional probability.

It is necessary to rise that the work, as an activity with a singular behaviour, must be understood not as a normal activity in the city, sons as a factor that is the human interface necessary for the functionality of cities. If this human interface does not exist, the city could not perform its functions (processing, trade, knowledge, etc). Hägerstrand named this restriction as “coupling restriction”

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